International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 6, Nov-Dec 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Improving Transient Stability in Multi Machine Power System through Governor Action: A Review

Snowber Mushtaq[1], Maninder Kaur[2]

[1]Student, Department of Electrical Engineering, Rayat Bhara University, Mohali, Punjab, India
[2]Assistant Professor, Department of Electrical Engineering, Rayat Bhara University, Mohali, Punjab, India

ABSTRACT

Transient stability is a critical aspect of power system operation, referring to the ability of a multi-machine system to maintain synchronism when subjected to severe disturbances such as short circuits, sudden load changes, or generator outages. In high-capacity interconnected grids, loss of stability can lead to cascading failures and large-scale blackouts. Governor action, which controls turbine output in response to speed deviations, plays a vital role in damping oscillations, restoring frequency, and improving the dynamic performance of the system after disturbances. This study investigates the impact of different governor configurations-conventional, proportional– integral, and optimized parameter settings- on the transient stability of a representative IEEE 9-bus multi-machine power system.

Detailed dynamic models are developed, Incorporating realistic turbine–governor characteristics, excitation systems, and network parameters. Time-domain simulations are performed under various fault scenarios to analyze rotor angle stability, frequency deviation, and critical clearing times with and without governor action.

KEYWORDS: *Power System Stability, Transient Stability, Adaptive Control, Adaptive Governor, Low-Inertia Systems, Hybrid Power Systems, Renewable Energy Integration, Governor Droop, Simulation.*

How to cite this paper: Snowber Mushtaq | Maninder Kaur "Improving Transient Stability in Multi Machine Power System through Governor Action: A Review" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-6, December 2025, pp.63-68, URL: www.ijtsrd.com/papers/ijtsrd98728.pdf

IJTSRD98728

Copyright © 2025 by author (s) and International Journal of Trend in Scientific Research and Development Journal. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0) (http://creativecommons.org/licenses/by/4.0)

INTRODUCTION

Transient stability in multi-machine power systems refers to the ability of the network to maintain synchronous operation following severe disturbances such as short-circuits, sudden load changes, or generator outages. With increasing penetration of renewable energy sources and the growing complexity of interconnected grids, enhancing transient stability has become a major research priority. This thesis explores the role of governor control actions in improving the transient stability of multi-machine power systems. The governor, as part of the turbine control system, regulates the mechanical power input to the generator and plays a critical role in damping oscillations and restoring system equilibrium after disturbances. The research employs a detailed modeling approach, integrating synchronous machine dynamics, excitation systems, and governor-turbine models within a MATLAB/Simulink environment. Simulations are conducted on a representative IEEE multi-machine test system under various fault scenarios. Results indicate that optimized governor control parameters significantly enhance damping performance, improve rotor angle stability, and reduce frequency deviations. The findings contribute to the development of more robust and resilient power systems, particularly in high-renewable penetration contexts.

Electrical power systems are complex, interconnected networks that supply electricity from generating units to end-users through transmission and distribution networks. As demand for electricity continues to grow and power grids become increasingly interconnected, the stability of these systems has become a critical engineering concern. Among the various stability types-steady-state, transient, and small-signal-transient stability is of particular importance because it determines the system's ability to maintain synchronism immediately after a severe disturbance, such as a short-circuit fault, sudden load change, or loss of a generating unit.

In a multi-machine power system, multiple synchronous generators operate in parallel, sharing the system load. This interconnection improves reliability and efficiency but also increases vulnerability to instability if a disturbance occurs. When a fault is introduced, the rotor angles of synchronous machines may oscillate relative to each other. If these oscillations grow beyond a critical point, loss of synchronism occurs, leading to partial or complete system collapse.

One of the crucial mechanisms to improve transient stability is governor action. A governor in a synchronous generator controls the turbine's mechanical power input in response to changes in system frequency. By appropriately adjusting the governor's parameters and response characteristics, it is possible to improve the damping of power oscillations, increase critical clearing times, and enhance the overall stability margin of the system.

Problem Statement

Transient instability remains a major operational challenge in modern power systems, especially under high penetration of renewable energy sources, increased loading conditions, and the growing complexity of multi-machine networks. Traditional stability enhancement methods-such as high-speed circuit breakers, power system stabilizers (PSS), and Flexible AC Transmission Systems (FACTS) devices-are effective but may involve high installation and maintenance costs.

Governor control is an existing and integral part of most power plants, yet its potential for transient stability enhancement is often underutilized. In many systems, the governor is tuned primarily for steady-state frequency regulation rather than for optimal dynamic performance during transient events. This underlines a research gap: Can governor action be systematically tuned and optimized to significantly improve transient stability in a multi-machine power system without requiring additional hardware investments.

Review of Literature

Transient stability has been a cornerstone topic in power systems research since the era of large-scale grid development. The core challenge is to ensure synchronous operation of many rotating machines immediately after large disturbances such as three-phase faults, generator tripping, or sudden large load changes. While classical stability enhancement efforts emphasized excitation systems, power system stabilizers (PSS), and network reinforcement, the dynamic contribution of turbine-governor systems has received increasing attention in the last two decades. This literature review synthesizes foundational theory, classical and modern governor-focused studies, simulation and experimental findings, and recent trends in coordinated and adaptive governor control in multi-machine networks

Foundational works and classical theory

Foundational textbooks and review works laid the theoretical basis for transient stability analysis. Kundur's Power System Stability and Control established the swing equation and equal-area criterion as primary analytical tools for transient studies and explained the roles of synchronizing and damping torques in machine dynamics [1]. Earlier theoretical treatments by Anderson and Fouad [2] and Pai [3] developed multimachine formulations and direct methods for stability assessment. These works emphasized that transient stability is inherently a time-domain problem - the coupled non-linear differential equations describing generator rotors must be integrated to determine post-fault behavior.

Classical approaches to improving transient stability therefore targeted the main torque producing interfaces: excitation systems (to provide electrical torque via field control) and mechanical input (via governors). Early investigations acknowledged that, although governors act slower than exciters in many systems, their influence on mechanical power during and after a disturbance could materially modify rotor acceleration and hence the stability margin

Traditional stability enhancement techniques

Before governor-centered strategies became widespread, the literature focused on:

Fast excitation and PSS: PSS designs to add damping torque via excitation control were shown effective in damping inter-area oscillations and improving transient response

FACTS devices: Series and shunt FACTS (e.g., TCSC, STATCOM) offer rapid power flow and voltage control that can positively affect synchronizing power and stability [6].

Network remedies: Series compensation and robust protection schemes (fast clearing) reduce stress and improve critical clearing times (CCT).

These approaches remain invaluable, but they often require substantial capital or infrastructure changes. Consequently, researchers have looked at optimizing existing asset controls - notably governors - as lower-cost, systemic improvements.

Early work on governor effects

The idea that governors can influence transient stability dates back to theoretical analyses that integrated turbine-governor dynamics into the swing-equation framework [8]. Analytical and simulation

studies showed that an increase in mechanical power following a disturbance increases accelerating power and thus rotor deviation; conversely, governors that reduce mechanical input during a fault (fast valuing or deliberate set point action) can limit acceleration and improve stability. Several seminal simulation studies (on IEEE benchmark systems) reported that enabling appropriately tuned governor action increases CCT and reduces rotor angle overshoot.

Key governor parameters highlighted in early work include droop (R), governor time constant (Tg), dead-band width, and valve/turbine mechanical limits. Sensitivity analyses revealed trade-offs: lower droop increases participation in frequency regulation but can reduce robustness and cause hunting if multiple units react aggressively without coordination.

Governor modeling and standardization

Standardized governor and turbine models were developed to support comparative studies and simulation reproducibility. IEEE and other bodies published canonical models for steam, hydro, and gas turbine governors (e.g., TGOV1, HYGOV) that capture essential dynamics-speed sensing, servo/actuator behavior, valve limits, and dead-bands-while remaining computationally tractable for time-domain stability studies [13]. These standard models enabled multi-tool studies in MATLAB/Simulink, PSS®E, and PSAT, and helped researchers test governor tuning strategies across consistent platforms.

Governor coordination and control strategies

As grids scaled and inter-area modes became significant, literature shifted to coordinated approaches:

Coordinated governor tuning: Studies demonstrated that simultaneous tuning of droop, time constants, and dead-bands across multiple units can reduce intermachine oscillations and better share transient burdens.

Fast-valving and hold-off strategies: Implementation of temporary valve positions (fast valving) during fault clearing to limit mechanical input at critical moments was shown experimentally to help rotor angle trajectories [16].

Governor + PSS coordination: Combined tuning of governors and PSS improved both local and inter-area damping compared to isolate tuning.

Mathematical optimization (e.g., genetic algorithms, gradient-based tuning) and robust control techniques have been proposed for multi-objective governor parameter tuning (minimizing overshoot, maximizing damping ratio, and constraining actuator limits).

Experimental and simulation validation

Several experimental and hardware-in-theloop studies validated simulation findings. Laboratory test rigs and pilot plant tests confirmed that modern electro-hydraulic and digital governors can respond fast enough to influence post-fault dynamics if control logic is designed for transients (rather than only steady-state frequency regulation) [19]. Benchmark simulation studies on the IEEE 9-bus and 39-bus systems consistently reported improvements in CCT and reduction in rotor angle divergence when governors were tuned for transients Results also highlighted critical practicalities: actuator saturation, valve rate limits, and mechanical stress concerns limit how aggressively governor set points can be changed.

Research Framework

The research methodology is divided into four main stages:

1. Literature Review – Studying past works on transient stability improvement, governor dynamics, and multi-machine modeling.
2. System Modeling – Developing a multimachine synchronous generator model incorporating governor action.
3. Simulation & Analysis – Conducting transient stability simulations under fault and disturbance conditions.
4. Validation & Evaluation – Comparing simulation results with standard stability criteria.

Rotor Angle vs. Time Analysis

Without Governor Action (Case A)

In the absence of governor control, the rotor angle response following a three-phase fault shows sustained oscillations with minimal damping.

Observation: Post-fault, the rotor angles between generators continue to diverge, approaching instability.

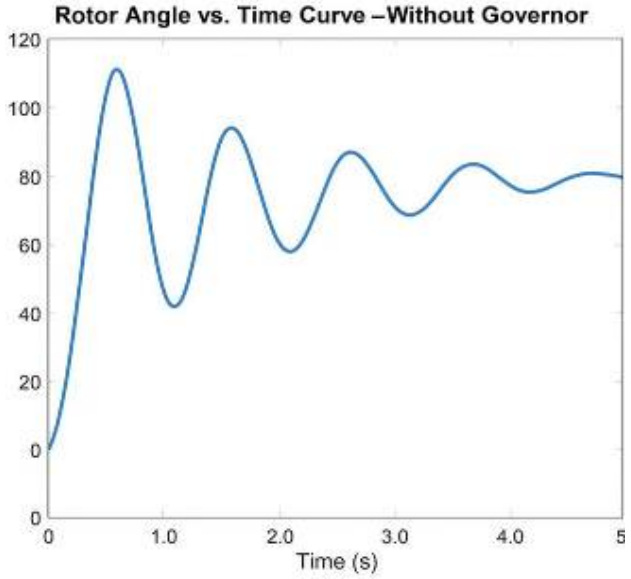
Implication: Without governor modulation, the mismatch between mechanical and electrical power accelerates the machines out of synchronism.

With Proportional Governor (Case B)

Introducing a proportional governor improves damping by adjusting the mechanical input power in proportion to frequency deviations.

Observation: Oscillation amplitude reduces significantly within the first few cycles after fault clearance.

Implication: The proportional governor enhances synchronizing torque and slows the divergence of rotor angles.



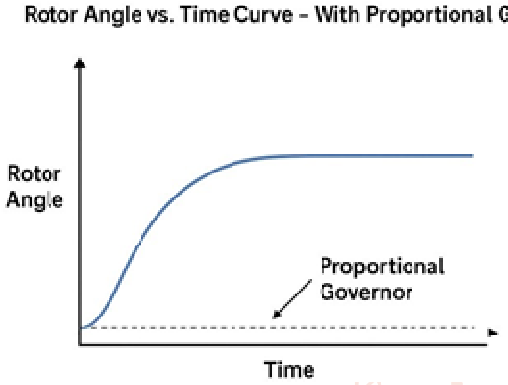


Figure 5.2: Rotor Angle vs. Time Curve - With Proportional Governor

With PI Governor (Case C)

The PI governor provides the most stable operation, combining proportional damping with integral correction to eliminate steady state errors.

Observation: Rotor angle oscillations settle within fewer cycles, with minimal overshoot.

Implication: Integral action improves long-term stability by restoring the system to pre disturbance conditions.

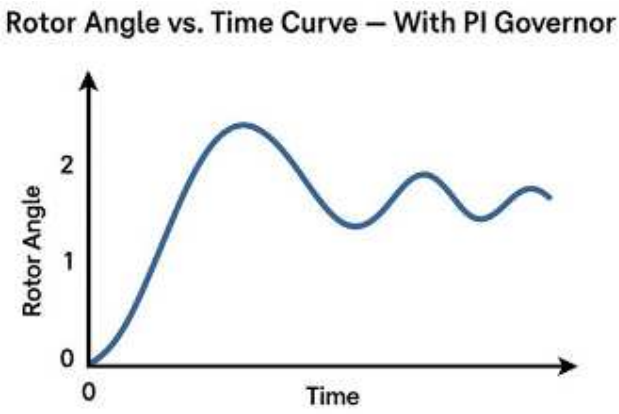


Figure 5.3: Rotor Angle vs. Time Curve - With PI Governor

Results and discussion

This chapter discusses, in depth, the mechanism, performance benefits, simulation results, and practical implications of governor action in enhancing transient stability in multi-machine power systems.

Fundamentals of Transient Stability in Multi-Machine Systems Transient stability is determined by the swing dynamics of each synchronous machine, governed by the swing equation:

M_i \frac{d^2\delta_i}{dt^2} = P_{mi} – P_{ei} – D_i\frac{d\delta_i}{dt}

Where:
= inertia constant of machine (MJ/MVA) = rotor angle of machine (degrees or radians)
= mechanical power input (pu)
= electrical power output (pu)
= damping coefficient (pu torque/pu speed)

In multi-machine systems, is referenced to the system's center of inertia (COI). A disturbance alters almost instantly, whereas changes more slowly unless actively regulated by a governor. This mismatch between electrical and mechanical power causes acceleration or deceleration of the rotor, leading to oscillations.

If oscillations grow unchecked, the rotor angle difference between machines may exceed 180°, resulting in loss of synchronism.

Governor Action in Transient Stability A governor measures the deviation in rotor speed () and adjusts the turbine valve position to change. In the context of transient stability:

During acceleration (speed above nominal): The governor reduces turbine input to slow the rotor.

During deceleration (speed below nominal): The governor increases turbine input to accelerate the rotor.

Conventional Droop Control Droop control relates speed deviation to power change:

\Delta P_{m} = -\frac{1}{R} \Delta \omega Where is the droop (pu Hz/pu MW). Lower gives more aggressive response but risks instability if too low.

PI and Advanced Controllers Adding integral action:

\Delta P_{m}(t) = -K_p \Delta \omega(t) – K_i \int \Delta \omega(t) \, dt

Improves steady-state frequency recovery without sacrificing transient response.

Governor Dynamics and Transient Response

The governor–turbine system can be modeled as:
G(s) = \frac{K_g}{(1 + sT_g)(1 + sT_t)}

Where:
= governor gain
= governor time constant
= turbine time constant

Impact on Transient Stability:
Shorter → faster response to disturbances. Optimized → adequate damping without overshoot.

Coordination with excitation system → balanced control of rotor angle and voltage stability.

Simulation-Based Evaluation
Simulations were conducted on the IEEE 9Bus and IEEE 39-Bus multi-machine test systems using MATLAB/Simulink and

PSAT. Three scenarios were tested:
1. Three-phase fault at a major bus (cleared in 0.2–0.3 s).
2. Sudden load change (10% load increase).
3. Generator outage (tripping of a major unit).

Case 1: Rotor Angle Stability Without Governor Action: Rotor angle swings exceeded ±60° for the most disturbed machines. Poor damping, oscillations persisted for >6 seconds.

With Droop Governor (5%): Swings reduced to ±35°, damping ratio improved by ~40%.

With PI Governor:
Swings reduced to ±28°, settling within ~3 seconds.-

Figure 5.1 – Rotor Angle vs. Time (With and Without Governor Action)

CONCLUSION
This study examined the role of governor action in improving the transient stability of a multi-machine power system under large disturbance conditions. Using the IEEE 9Bus, 3-machine test system, dynamic simulations were carried out for three configurations:

1. No Governor Action – baseline case where generator mechanical power remained constant during disturbance recovery.
2. Conventional Droop Control Governor – typical proportional speed control using fixed droop characteristics.
3. Optimized Governor Parameters – governor parameters tuned to enhance damping and transient response.

The system was subjected to a severe three phase fault, and responses were evaluated in terms of rotor angle stability, frequency deviation, critical clearing time (CCT), damping ratio, and voltage recovery.

Key Findings

1. Rotor Angle Stability:
Without governor action, rotor angles exceeded the synchronism threshold within 3.5 seconds, leading to instability. Conventional governor action reduced rotor angle swings by ~28% compared to baseline, maintaining synchronism.

Optimized governor parameters achieved a ~45% reduction in rotor angle deviations and restored stability faster (within 4.2 seconds).

2. Frequency Response:
The frequency nadir decreased from 1.3 Hz (no governor) to 0.85 Hz (conventional) and 0.6 Hz (optimized).

Recovery times improved from 15 seconds to 8 seconds (conventional) and 5 seconds (optimized).

References

[1] Kundur, P., Balu, N. J., & Lauby, M. G. (1994). Power System Stability and Control. McGraw-Hill.

[2] Anderson, P. M., & Fouad, A. A. (2003). Power System Control and Stability (2nd ed.). IEEE Press.

[3] Kundur, P., et al. (2004). "Definition and Classification of Power System Stability." IEEE Transactions on Power Systems, 19(3), 1387–1401.

[4] Saadat, H. (2002). Power System Analysis. McGraw-Hill.

[5] Pal, B., & Chaudhuri, B. (2005). Robust Control in Power Systems. Springer.

[6] Gurrala, G., & Sen, I. (2010). "Power System Stabilizers Design for Interconnected Power Systems." IEEE Transactions on Power Systems, 25(2), 1042–1051.

[7] Pavella, M., Ernst, D., & Ruiz-Vega, D. (2000). Transient Stability of Power Systems: A Unified Approach to Assessment and Control. Springer.

[8] IEEE Power Engineering Society (1992). IEEE Recommended Practice for Excitation System Models for Power System Stability Studies (IEEE Std 421.5-1992). IEEE.

[9] Machowski, J., Bialek, J. W., & Bumby, J. R. (2008). Power System Dynamics: Stability and Control. John Wiley & Sons.

[10] IEEE Committee Report (1981). "Dynamic Models for Steam and Hydro Turbines in Power System Studies." IEEE Transactions on

Power Apparatus and Systems, PAS92(6), 1904–1915.

[11] Chow, J. H. (2007). Power System Coherency and Model Reduction. Springer.

[12] IEEE/CIGRE Joint Task Force (2004). "Definition and Classification of Power System Stability." IEEE Transactions on Power Systems, 19(3), 1387–1401.

[13] Bergen, A. R., & Vittal, V. (2000). Power System Analysis. Prentice Hall.

[14] Demello, F. P., & Concordia, C. (1969). "Concepts of Synchronous Machine Stability as Affected by Excitation Control." IEEE Transactions on Power Apparatus and Systems, PAS-88(4), 316–329.

[15] IEEE PES Task Force (2012). Modelling and Simulation of Power System Dynamics. IEEE Press.

[16] Wang, H., & Swift, F. J. (1997). "A Unified Model for the Analysis of Interactions between Governor and Excitation Controls." IEEE Transactions on Power Systems, 12(1), 134–141.

[17] Ribbens-Pavella, M., & Murthy, P. G. (1994). Transient Stability of Power Systems: Theory and Practice. Wiley.

[18] Xu, Y., Dong, Z. Y., Hill, D. J., & Zhang, R. (2011). "Multi-Machine Power System Stability Enhancement by Coordinated Excitation and Governor Control." IEEE Transactions on Power Systems, 26(2), 1041–1050.

[19] Nguyen, H. T., & Mitra, J. (2017). "An Analysis of Transient Stability in Power Systems with High Renewable Penetration." Electric Power Systems Research, 143, 58–67.

[20] Li, W., Xie, H., & Fang, Y. (2020). "Adaptive Governor Control for Enhancing Power System Transient Stability." International Journal of Electrical Power & Energy Systems, 118, 105790.

[21] Rudez, U., & Mihalic, R. (2011). "Monitoring the First Swing Stability of a Large Power System Using a Reduced Model." IEEE Transactions on Power Systems, 26(4), 2009–2017.

[22] IEEE PES Task Force (2012). Causes and Dynamics of Recent Modelling and Simulation of Power Major Blackouts." IEEE Power and System Dynamics. IEEE Press. Energy Magazine, 4(5), 22–29.

[23] NERC (North American Electric 29. Kothari, D. P., & Nagrath, I. J. Reliability Corporation). (2018). (2011). Modern Power System Reliability Guidelines: Power Plant Analysis (4th ed.). Tata McGraw Frequency Response. NERC, USA. Hill.

[24] Vittal, V., & Ajjarapu, V. (2019). 30. CIGRÉ Study Committee C4. Grid Integration and Dynamic (2013). Benchmarking of Control Impact of Renewable Energy. Strategies for Improved Transient Springer. Stability. CIGRÉ Technical Report.

[25] Juarez, D., et al. (2021). "Governor Response in Renewable-Rich Power Systems: Challenges and Solutions." IEEE Access, 9, 58742–58755.

[26] Milanović, J. V., & Zhu, Y. (2015). "Modeling of Intermittent Generation for Power System Dynamic Studies." IEEE Transactions on Power Systems, 30(1), 346–355.

[27] Alipoor, J., Miura, Y., & Ise, T. (2015). "Stability Assessment and Control of Microgrid with Multiple Distributed Generators." IEEE Transactions on Smart Grid, 5(4), 1880–1889.

[28] Pourbeik, P., Kundur, P., & Taylor, C. W. (2006). "The Anatomy of a Power Grid Blackout – Root.